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Method for monitoring traffic state for a traffic network with effective bottlenecks

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The invention is related to a method for monitoring, including predicting the traffic state in a traffic network with effective bottlenecks, in particular in a corresponding road traffic network, according to the preamble of Claim 1. In this case, effective bottlenecks are to be understood both as bottlenecks in the actual sense, that is to say a reduction in the number of usable lanes, and bottlenecks in the wider sense which, for example, are caused by one or more incoming feeder lanes or by a bend, a grade, a downgrade, a division of a lane into two or more lanes, one or more exits or a bottleneck moving slowly (by comparison with the average vehicle speed in free traffic), for example owing to a vehicle which is being driven slowly.

Methods for monitoring and predicting the traffic state in a traffic network, for example a road traffic network, are variously known and of particular interest also for diverse telematics applications in vehicles. One aim of these methods is to obtain from the traffic measured data detected at traffic measuring points a qualitative description of the traffic state at the respective measuring point and its surroundings. Measuring points in this sense are presently both measuring points installed in a stationary fashion on the route network side, and moveable measuring points such as are represented, for example, by sample vehicles floating along in the traffic (so-called "floating cars") or by a measurement of the traffic flow obtained by means of monitoring from deep space, space or the air.

For the purpose of qualitative description of the traffic state, it is known to divide the latter into various phases, for example into a phase of "free traffic", in the case of which relatively fast vehicles can overtake without a problem, a phase of "synchronized traffic", in the case of which possibilities for overtaking scarcely exist, but a high traffic intensity still prevails, and a phase of "congestion", in the case of which the vehicles are virtually stationary and also the traffic intensity drops to very low values - see, for example, the journal article by B.S. Kerner and H. Rehborn, "Experimental properties of complexity in traffic flow", Physical Review E 53, R 4275, 1996. In this case, the phase of synchronized traffic is to be understood both as a state in the case of which, owing to the fact that there are scarcely any possibilities of overtaking in this phase, all vehicles in different lanes are driven at a very similar, "synchronized" speed, as is, for example, the case in particular on route sections without approach roads and exits, a traffic state in the case of which the distribution of speed for the vehicles in different lanes can still differ, but there is a tendency for synchronization of the speeds of those vehicles in different lanes which are respectively being driven on an identical route, since there are scarcely any possibilities of overtaking with reference to one driving route. The phase division is based on the idea of selecting the phases such that each of them corresponds to specific characteristic properties of the traffic flow, such that it is possible to estimate the temporal and spatial extent of route sections in which the traffic state is in a specific phase. In the journal article by B.S. Kerner, "Experimental Features of Self-Organization in Traffic Flow", Physical Review Letters, Vol. 81, No. 17, page 3797, so called "pinch regions"

(regions of "congested synchronized traffic") are selected in the phase of "synchronized traffic", and are subsequently treated specially. These are regions inside synchronized traffic in which it is possible to drive only at very low speeds and in which there is spontaneous formation of short-lived congestion states which can migrate upstream and grow in the process, and which can then possibly lead to a lasting congestion state.

Various methods are already known for monitoring and predicting the traffic state "congestion point" -see the automatic congestion dynamics analysis described in Laid-Open Application DE 196 47 127 A1, whose content is incorporated herein by reference, and methods known from the literature mentioned there.

In the older German Patent Application No. 198 35 979.9, which is not a prior publication and whose content is incorporated herein by reference, there is, moreover, a description of the monitoring and prediction of synchronized traffic, in particular the detection of the phase transition between free and synchronized traffic, and a prediction of the spatial extent of synchronized traffic by inferring the position of the upstream edge of the latter by virtue of the fact that for a corresponding upstream measuring point specific conditions for an induced upstream phase transition from free to synchronized traffic are no longer fulfilled, or widespread congestion has arisen. This method is particularly suitable for detecting the start of a phase of synchronized traffic at an effective bottleneck of the traffic network, and for tracking the temporal development of the synchronized traffic forming upstream of this bottleneck, the downstream edge of which generally remains fixed at the effective bottleneck. An edge fixed at the effective bottleneck is understood in this case as one which

remains in the surroundings of this bottleneck, that is to say remains essentially stationary in the surroundings of a stationary effective bottleneck, or moves along essentially synchronously with a moveable effective bottleneck. The location of the effective bottleneck is therefore the one where the downstream edge of the synchronized traffic is momentarily located.

In a German patent application (our file P032254/DE/1) submitted in parallel, whose content is incorporated herein by reference, there is a description of a traffic, state monitoring method in the case of which the current traffic state is monitored with regard to different state phases and, in particular, with regard to synchronized traffic and a pinch region as well as the phase transition between states of synchronized traffic, on the one hand, and free traffic, on the other hand, and the future traffic state is predicted on this basis, if required. In particular, this method can be used to estimate the edges of regions of synchronized traffic relatively accurately for current points in time or to predict for future points in time at which said edges are not or will not be located at a measuring point, but somewhere between two measuring points. A suitably designed fuzzy logic is preferably used in this case.

As a technical problem, the invention is based on the provision of a method of the type mentioned at the beginning with the aid of which the current traffic state can be monitored comparatively reliably specifically even in the region upstream of effective bottlenecks, and a comparatively reliable prediction of the future traffic state is also possible on this basis, if required.

The invention solves this problem by providing a method with the features of Claim 1. This method is distinguished, in particular, in that the traffic state upstream of a respective effective bottleneck of the traffic network is classified as a pattern of dense traffic when an edge fixed at the relevant effective bottleneck is detected between downstream free traffic and upstream synchronized traffic, that is to say when dense traffic forms upstream of the bottleneck. The pattern classification of the traffic state includes a division of the traffic upstream of the bottleneck into one or more regions, consecutive upstream, of different state phase composition. Moreover, the pattern classification includes a profile, dependent on state phase, time and location, of traffic parameters taken into account for the state phase determination, such as average vehicle speed, traffic flow and/or traffic density.

In the case of increasing traffic, specifically at effective bottlenecks which can mostly be stationary bottlenecks but also, in some incidences, moveable bottlenecks such as very slowly moving road-construction or road-maintenance vehicles or migrating building sites, a formerly free traffic state will frequently be initially transformed into the so-called region of synchronized traffic upstream of the bottleneck, whilst resulting, depending on further traffic, in a pattern, typical of the bottleneck, of dense traffic. In the minimum version, this pattern can comprise only the region of synchronized traffic adjoining the effective bottleneck upstream. The formation of a pinch region is additionally observed in the case of increasing traffic volume and/or appropriate route infrastructure. Congestion points can develop from this pinch region and propagate upstream, it being possible for free or synchronized traffic or a pinch region to be present between each two congestion

points. The region in which the widespread congestion propagating upstream (by contrast with the localized congestion occurring in pinch regions) is situated is denoted as a region of "moving widespread congestion".

As a result of these findings, in the case of detection of synchronized traffic moving upstream of a bottleneck it is possible by means of the method according to the invention to use comparatively fewer current or predicted measured traffic data to assign the traffic state to a fitting pattern typical of the respective bottleneck. The further analysis or evaluation and, specifically, also the prediction of the traffic state to be expected in future can then be performed on the basis of this pattern recognition with the aid of comparatively little data material which is to be processed, and consequently with correspondingly slight computation outlay. A further essential advantage of this method consists in that, by contrast with mathematical traffic state models with many parameters which are to be validated, it includes a pattern-based modelling without parameters to be validated.

A method developed according to Claim 2 permits the pattern classification of the traffic state even for the case in which a pattern, arising initially at an effective bottleneck, of dense traffic has extended beyond one or more further, upstream effective bottlenecks. It is seen that the pattern classification is also possible for this case, and the overarching pattern is built up from the same regions as an individual pattern including only one effective bottleneck, that is to say the overarching pattern also comprises the characteristics of regions of "synchronized traffic", "pinch regions" and "moving widespread congestion".

In a method developed according to Claim 3, the pattern determined as a function of time and location for a respective bottleneck is determined empirically from recorded traffic measured data and stored in a fashion which can be called up. As a result, it is possible at any later point in time at which a fixed edge is detected at the bottleneck between downstream free traffic and upstream synchronized traffic to select the pattern profile which best fits the measured traffic data currently recorded or predicted for the relevant point in time from the stored pattern profiles, and to use it as current or predicted traffic state for the corresponding route section of the traffic network upstream of the bottleneck.

In the case of a method developed according to Claim 4, the dense traffic state upstream of an effective bottleneck is distinguished as a function of vehicle influx in accordance with three pattern variants, and each of the three variants is assigned a corresponding time- and location-dependent pattern profile for one or more of the important traffic parameters of "mean vehicle speed", "traffic flow" and "traffic density". In the case of a first variant, the pattern comprises only one region of synchronized traffic. In the case of a second variant, the pattern additionally comprises a pinch region adjoining upstream, and in the case of a third pattern variant there is in addition a region of moving widespread congestion upstream of the pinch region. The associated, generally time-dependent edge positions between the various pattern regions are determined by respectively suitable methods, for example of the type mentioned at the beginning.

A method developed according to Claim 5 permits the detection and tracking of overarching patterns of dense traffic in the considered traffic network as a function of the vehicle flows. In particular, the location and

time of the resolution of a respective overarching pattern and the sequence of the individual regions of "synchronized traffic", "pinch region" and "moving widespread congestion" can be determined in each overarching pattern as a function of the vehicle flows. Moreover, the temporal and spatial characteristic of congestion points propagating upstream by means of regions of synchronized traffic and/or pinch regions can be predicted when a region of "moving widespread congestion" overlaps in an overarching pattern with regions of synchronized traffic and/or pinch regions.

In a further refinement of this measure of determining the edge position, the method according to Claim 6 provides a temporal tracking of the positions of diverse edges between the various pattern regions and/or congestion points in overarching patterns and/or the detection of newly occurring overarching patterns, with the result that the position and extent of each of the regions, which differ in their state phase composition, of an individual or overarching pattern can be tracked in temporal development.

In the case of a method developed according to Claim 7, the travel time expected to be required for transversing the route section in which the individual or overarching pattern of the dense traffic is located is additionally determined as a function of time and stored. The stored travel time information can be used, for example, directly within the framework of a method for estimating travel times, currently to be expected or to be expected in future for prediction, for travelling specific, prescribable routes of the traffic network.

In a development of the method according to Claim 8, the positions of associated edges and the influx to the pattern are detected currently after detection of an

individual or overarching pattern. This information is used to select the pattern profile which best fits therewith from the stored pattern profiles, and to carry out a prediction on the further development of the pattern of dense traffic at the relevant effective bottleneck. This can comprise, in particular, a prediction of relevant traffic state parameters such as average vehicle speed, traffic flow and/or traffic density and, if required, also be travel time to be expected.

Advantageous embodiments of the invention are illustrated in the drawings and described below. In the drawings:

Figure 1 shows a diagrammatic illustration of a route section of a road traffic network with an effective bottleneck, and of an upstream pattern of dense traffic, which comprises a region of synchronized traffic,

Figure 2 shows an illustration according to Figure 1, but for a pattern of dense traffic which additionally includes a pinch region,

Figure 3 shows an illustration according to Figure 2, but for a pattern of dense traffic which additionally includes a region of moving widespread congestion,

Figure 4 shows a diagrammatic illustration of a determination of current and future traffic states at a measuring point for the purpose of monitoring and predicting traffic states including patterns of dense traffic upstream of bottlenecks, and

Figure 5 shows a view corresponding to Figure 4, but for the case of an edge, situated between two measuring points, between free and synchronized traffic.

Figure 1 illustrates by virtue of example a route section of a directional lane of a road traffic network such as, for example, a motorway section, whose traffic state is estimated, for example, by a traffic centre for the current point in time, that is to say determined by computer, and is predicted for future points in time. Permanently installed and/or moveable measuring points are provided, as required, in order to detect measured traffic data serving this purpose. The measured data are received as appropriate by the traffic centre and appropriately evaluated by a computation unit there. Reference may be made for further details of the implementation of such traffic state monitoring systems to the literature quoted at the beginning and, in particular, also to the German patent application mentioned there and submitted in parallel.

Characteristic of the present traffic state monitoring system is the implementation of a monitoring method which comprises detection of typical pattern profiles of dense traffic upstream of effective bottlenecks and classification of the same, with the aid of which it is then possible for the current traffic state to be estimated comparatively easily and reliably, and likewise to predict the traffic state to be expected in future in this route region.

Figure 1 shows the case of an example in which an effective bottleneck is located at a route position $x_{S,F}$ and, owing to correspondingly high traffic volume, an edge $F_{S,F}$ fixed there has formed between a downstream

region B_F of free traffic and an upstream region B_S of synchronized traffic. The formation of such an edge $F_{S,F}$ can be detected, for example, with the aid of the method described in the above-named German Patent Application No. 198 90 35 979.9. In this case, it can be a spatially fixed bottleneck such as, for example, a permanent lane reduction at this point, but it can also be a moveable bottleneck, as formed, for example, by a "migrating building site" or very slowly moving road-construction vehicles.

In the case of the detection of such a fixed edge $F_{S,F}$ between downstream free traffic B_F and upstream synchronized traffic B_S, the method then classifies the traffic state upstream of the effective bottleneck into a pattern of dense traffic. This uses the experimentally observed fact that in the case of increased traffic volume entirely typical pattern profiles of dense traffic form upstream of such effective bottlenecks, that is to say the traffic state there can be classified into certain typical variants of a pattern of dense traffic.

Treating the traffic state in this region as a pattern of dense traffic then permits a comparatively reliable prediction of the future traffic state and of the travel time required to traverse this region with a relatively low computational outlay and relatively few items of measured data information. For this purpose, a specific pattern of the dense traffic is assigned upstream of the respective effective bottleneck, in particular at all points with approach roads, on the basis of measurements of the traffic, that is to say measurements of traffic parameters representative of the traffic state. Such a pattern of dense traffic includes appropriate time-dependent and location-dependent profiles of the considered traffic parameters such as the average vehicle speed, the traffic flow

and/or the traffic density, and preferably also the travel time corresponding to the pattern respectively present. It is to be seen that these temporal/spatial profiles of the pattern of dense traffic deviate clearly, by more than a prescribed measure, from the corresponding profiles of free traffic. It is to be seen, furthermore, that the temporal/spatial profiles, respectively assigned to the pattern of dense traffic, of the traffic parameters considered such as the average vehicle speed, the traffic flow and/or the traffic density, and the travel time belonging to the pattern have characteristic properties in the case of each effective bottleneck. These properties are characteristic in the sense that they can be reproduced and predicted for different times, for example different times of day and/or different days, that is to say that these characteristic properties, including their characteristic time dependence, can be predicted without validating the parameters of a traffic prediction model used.

As has been said, in the example of Figure 1 the pattern of dense traffic comprises solely the region B_S of synchronized traffic with a downstream edge $F_{S,F}$ at the location $x_{S,F}$ of the effective bottleneck and an upstream edge $F_{F,S}$, whose position $x_{F,S}$ is determined by measurement and computation and tracked for its temporal development, and which is adjoined upstream by a further region B_F of free traffic.

A further, typically occurring variant of the pattern of dense traffic is illustrated in Figure 2 and includes, in addition to the region B_S of synchronized traffic, a pinch region B_{GS} adjoining upstream at the upstream edge $F_{GS,S}$ thereof. In the case of such a pinch region (region of congested synchronized traffic), narrow congestion points arise in otherwise synchronized traffic, but they are not individually

tracked. In order to divide the traffic state into the state phases of "free traffic", "synchronized traffic" with or without "pinch regions" and "congestion point", see also the abovementioned, parallel German patent application in which suitable measures are also specified for temporal tracking of the position $x_{GS,S}$ of the downstream edge $F_{GS,S}$, and the position $x_{F,GS}$ of the upstream edge $F_{F,GS}$, at which a region B_F of free traffic adjoins upstream in turn.

Given an appropriately large traffic volume and/or an appropriate route infrastructure, a pattern of dense traffic as illustrated in Figure 3 can be formed as a further, fully expressed variant. In addition to the region B_S of synchronized traffic and the pinch region B_{GS} adjoining upstream thereof, this comprises a region B_{St} adjoining upstream thereof of moving widespread congestion which is finally adjoined upstream again by a region B_F of free traffic. In other words, the presently classified pattern of dense traffic upstream of an effective bottleneck generally comprises the three regions, occurring consecutively upstream, of synchronized traffic B_S, congested synchronized traffic (pinch region) B_{GS} and moving widespread congestion B_{St}, of which Figures 2 and 1 show reduced forms in which the region B_{St} of "moving widespread congestion" and, additionally, the pinch region B_{GS} are lacking, something which is the case, in particular, in the starting phase of the complete pattern of Figure 3. In other words, the complete pattern according to Figure 3 is formed upstream of an effective bottleneck typically in the sequence of Figures 1 to 3 by virtue of the fact that the region B_S of synchronized traffic firstly arises at the effective bottleneck, and the pinch region B_{GS} and possibly also the region B_{St} of moving widespread congestion are then formed upstream of said region B_S when the traffic volume remains sufficiently

large and/or is permitted by the infrastructure of the corresponding route section.

The region B_{St} of moving widespread congestion comprises individually trackable widespread congestion which propagates upstream such as, for example, the congestion points S1, S2, S3, of which the congestion point S3 situated furthest upstream represents the last congestion point at the point in time considered. In this case, the state phase of "congestion point" is understood, as usual, as a structure, moving upstream, of the traffic flow in the case of which both congestion point edges move counter to the driving direction. Within the state phase of "congestion point", both the average vehicle speed and the traffic flow are very small. In the course of time a plurality of mutually spaced congestion points S1, S2, S3 are frequently formed upstream of the pinch region B_{GS}, which consequently form the region B_{St}, adjoining upstream, of "moving widespread congestion". Between the individual congestion zones S1, S2, S3, the traffic state can have the state phase of free traffic and/or synchronized traffic with or without pinch regions. The position $x_{F,St}$ of the upstream edge $F_{F,St}$ of the last upstream congestion point S3 forms the transition to the region B_F of free traffic adjoining upstream.

In order to classify the patterns relative to the respective effective bottleneck, the first step in applying the present method is to select all points in the traffic network where effective bottlenecks are located. After, the experimental traffic data are used as a basis for allocating either the "complete" pattern or one of the two said "abridged" patterns to each effective bottleneck, depending on the traffic volume in the surroundings of the effective bottleneck. Each of these patterns additionally includes an associated time-dependent and/or location-dependent profile of the

various traffic parameters such as, for example, the average vehicle speed, the vehicle density, the travel time, etc. These time-dependent and/or location-dependent profiles are determined not only by the pattern, but also by the respective effective bottleneck.

As mentioned above, in the case of the present traffic monitoring method the temporal/spatial profile of the pattern, typical of this bottleneck, of dense traffic is determined in advance empirically with the aid of appropriate traffic measurements in the region upstream of the respective effective bottleneck, and stored, in particular with regard to temporal/spatial profiles of the essential traffic parameters considered, such as the average vehicle speed and/or the traffic flow and/or the traffic density. For this purpose, it is established and stored for various values of the influx to the relevant bottleneck whether the pattern relating to the appropriate point in time comprises only the region B_S of synchronized traffic corresponding to Figure 1, the region B_S of synchronized traffic and the pinch region B_{GS} in accordance with Figure 2, or all three different pattern regions B_S, B_{GS} and B_{St} in accordance with Figure 3. For each of these three pattern variants, the temporal/spatial profile of the average vehicle speed, the traffic flow and/or the traffic density is assigned and stored. In addition, the travel time to be expected is preferably determined and stored for each of these three pattern variants for the respective effective bottleneck. Specifically, for each bottleneck and for the various influxes to the relevant bottleneck, the position $x_{S,F}$ of the downstream edge $F_{S,F}$ of the region B_S of synchronized traffic, that is to say the location of the effective bottleneck, the position $x_{GS,S}$ of the edge $F_{GS,S}$ between the region B_S of synchronized traffic and the pinch region B_{GS} adjoining upstream, and the position $x_{St,GS}$ of the edge $F_{St,GS}$

between the pinch region B_{GS} and the region B_{St} adjoining upstream, of moving widespread congestion are determined as a function of the influx to each of the said edges and stored.

In the current traffic state monitoring operation, after establishing an edge $F_{S,F}$, fixed at an effective bottleneck, between a downstream region B_F of free traffic and a region B_S of synchronized traffic forming upstream, the position $x_{F,S}$ of the upstream edge $F_{F,S}$ thereof, which in accordance with Figure 1 is adjoined, in turn, by a region B_F of free traffic is then determined. In addition, the influx to this edge $F_{F,S}$ or as an alternative to this, the influx to the associated effective bottleneck is detected. With the aid of these input data, the best-fitting pattern variant of dense traffic is then selected from the store and used, in particular the associated temporal/spatial profile of the average vehicle speed, traffic flow and/or the traffic density and the associated time-dependent travel time. Starting from the currently selected pattern profile, a prediction of the further development of the pattern is then made with the aid of the continuously determined current position $x_{F,S}$ or the edge $F_{F,S}$ between the region B_S of synchronized traffic and the region B_F, adjoining upstream, of free traffic, and with the aid of the influxes to the respective bottleneck. This includes, in particular, a prediction as to whether there will form from the initial pattern in accordance with Figure 1 one of the two other pattern variants in accordance with Figures 2 and 3, and/or when and how the pattern of dense traffic will form back again into the state of free traffic at the relevant effective bottleneck.

When, predicted currently or for the future, the pattern of dense traffic at the respective bottleneck also contains the pinch region B_{GS} in accordance with

Figure 2, the positions $x_{St,GS}$, $x_{GS,S}$ of the two edges $F_{St,GS}$, $F_{GS,S}$ limiting this region B_{GS} are then also determined continuously for this region as, for example, described in the abovementioned, parallel German patent application. In addition, the associated influx to the bottleneck considered is determined, in turn. This output information is then used in turn, to select from the stored pattern profiles that pattern variant and the corresponding temporal/spatial profile of the traffic parameters considered and of the travel time to be expected from the stored patterns which best fits these input data. On the basis of the selected pattern profile, an improved prediction of the temporal/spatial profile of the traffic parameters considered, such as in particular, the average vehicle speed, the traffic flow and/or the traffic density, and the associated time-dependent travel time is then made.

When the currently present or the predicted pattern also contains the region B_{St} of moving widespread congestion, the temporal development of the individual congestion points S1, S2, S3 there is tracked by means of a method, applied upstream of the upstream edge $F_{St,GS}$ of the pinch region B_{GS}, for dynamic congestion tracking and prediction, as described, for example, in the abovementioned DE 196 47 127 A1, and the congestion points are appropriately considered when determining the associated travel time to be expected.

It is seen that the above-described method according to the invention can be used with a relatively low computation outlay to currently estimate the traffic state upstream of effective bottlenecks even in the case of a relatively large traffic volume, and to make a prediction for the future by using a pattern recognition process which utilizes the empirically observed fact that a characteristic pattern of dense traffic forms upstream of such effective bottlenecks in

the case of a relatively large traffic volume. This pattern comprises at least one region of synchronized traffic adjoining the effective bottleneck upstream, possibly a pinch region adjoining upstream and, in addition, when it is fully expressed, an adjoining region of moving widespread congestion. By using suitable calculating methods, the edges of the individual pattern regions and the respectively associated temporal/spatial profiles of the important traffic parameters representative of the traffic state, such as average vehicle speed, traffic flow and traffic density, can be estimated and predicted very reliably. Moreover, this offers the possibility of comparatively reliable predictions of travel time for trips made via such effective bottlenecks.

Whereas the above description of the method considered the case of a pattern of dense traffic forming at an effective bottleneck without influencing further effective bottlenecks, the present method is also suitable for the case of a plurality of effective bottlenecks involved in a pattern of dense traffic, and this will be explained in more detail below. This case arises when the upstream end of a pattern belonging to a first effective bottleneck reaches the position of a second effective bottleneck which is situated closest upstream to the first effective bottleneck. Depending on the development of the pattern of dense traffic, it is possible in addition to the second effective bottleneck to incorporate one or more further effective bottlenecks, which are consecutive upstream, into such an extended pattern of dense traffic. The patterns, extending beyond a plurality of effective bottlenecks, of dense traffic may be denoted as "overarching" patterns of dense traffic, by contrast with the pattern of dense traffic which is to be denoted as an "individual pattern" and contains only respectively one effective bottleneck.

The development of such an overarching pattern starts at the point in time in which the upstream end of a first pattern, belonging to the said first, downstream effective bottleneck, reaches the position of the second effective bottleneck, situated closest upstream. Since the production of synchronized traffic from free traffic at each effective bottleneck is a phase transition of "first order" which arises from every interruption of the traffic which is greater than a critical interruption, the occurrence of the upstream end of the first, downstream pattern of dense traffic can trigger this phase transition. This phase transition occurs when, depending on the traffic volume and the route infrastructure, the state of free traffic at the upstream effective bottleneck was already unstable in any case with the result that the occurrence of the upstream end of the pattern, belonging to the first effective bottleneck, of dense traffic "triggers" the phase transition there. As a result of this phase transition, a region of synchronized traffic or a pinch region is then formed in turn upstream of the upstream, second effective bottleneck.

In the case when the pattern, occurring at the upstream effective bottleneck, of dense traffic is one of the reduced forms shown in Figures 1 and 2, this last-mentioned region combines with the region of synchronized traffic or the pinch region of said pattern such that an overarching pattern is formed which is regarded as a newly arising pattern jointly assigned to the two effective bottlenecks, and which is developed further in a fashion similar to an "individual" pattern. The development of the overarching pattern, that is to say the temporal and spatial development of the edges of the various pattern regions, is then in this case a function of the

properties of the two effective bottlenecks incorporated. As in the case of the "individual" pattern, the overarching pattern allocated to the two bottlenecks is stored with the corresponding time-dependent and/or location-dependent profile of the various traffic parameters considered, and is taken into account in the further monitoring and prediction of traffic states.

The procedure outlined for incorporating an effective bottleneck which is respectively next upstream, which is achieved by a downstream pattern of dense traffic, is carried out upstream successively for all effective bottlenecks from one effective bottleneck to the next. It is possible thereby to allocate to a traffic network one or more overarching patterns which in some cases can achieve a substantial extension of, for example, several tens or even hundreds of kilometres. Each overarching pattern comprises a sequence of complete individual patterns corresponding to Figure 3 and/or reduced patterns corresponding to Figures 1 and 2. Moreover, an overarching pattern can also have a form in which a region of "moving widespread congestion", which has arisen in a pattern, situated downstream, of dense traffic, overlaps with a region of synchronized traffic and/or a pinch region in a pattern, situated upstream, of dense traffic. This is possible by virtue of the fact that moving widespread congestion passes through freely upstream both by means of synchronized traffic and by means of pinch regions. Moreover, the speed of the downstream edge of each instance of moving widespread congestion is a characteristic quantity whose mean value does not depend on whether an instance of moving widespread congestion passes through by means of free traffic or by means of synchronized traffic or by means of pinch regions.

Since a plurality of regions of moving widespread congestion of various "full" patterns of dense traffic can arise simultaneously in relation to corresponding effective bottlenecks, a plurality of overlaps of the various regions of moving widespread congestion with regions of synchronized traffic and/or pinch regions can exist in an overarching pattern. In this case, the congestion points in each region of "moving widespread congestion" always move upstream, and their temporal development can be observed with the aid of one of the abovementioned conventional congestion tracking methods, as a result of which it is possible to track the temporal characteristic of the overlaps correspondingly. This information on the temporal variation of the overarching pattern from the movement of the various congestion points is likewise stored as belonging to the overarching pattern of dense traffic, and can be taken into account by appropriately calling up the overarching pattern for a prediction of the traffic in the traffic network considered.

This mode of procedure is based on the finding that congestion points move upstream as self-contained traffic objects by means of the traffic with the state phases of free traffic or synchronized traffic. When, thus, a region of moving widespread congestion of a pattern, belonging to one or more downstream effective bottlenecks, of dense traffic arrives at an upstream effective bottleneck, widespread congestion points thereat easily move further beyond the upstream effective bottleneck. However, when the preconditions required therefor with regard to traffic volume and bottleneck characteristics are fulfilled, they can trigger the phase transition from free to synchronized traffic if no synchronized traffic has yet occurred. This phase transition therefore occurs relatively easily, because the maximum traffic flow beyond the bottleneck in the state of synchronized traffic is

lower than in the state of free traffic. Given free traffic with sufficiently high traffic flow, even a relatively small traffic interruption such as is represented, for example, by widespread congestion passing through is enough to "trigger" transition into the state of synchronized traffic.

If, now, a region of moving widespread congestion as upstream region of a "full" individual pattern or as a corresponding subregion of an overarching pattern has reached with its upstream end the upstream neighbouring effective bottleneck and triggered the formation there of synchronized traffic, an individual or overarching pattern having the structures in accordance with Figures 1 to 3 can form in turn upstream of this bottleneck when this is induced by the traffic volume and the route infrastructure, it being possible for this pattern formation to be accomplished or developed further virtually independently of the pattern structure at effective bottlenecks situated downstream.

The production of regions of synchronized traffic or pinch regions and of regions of moving widespread congestion can be understood and detected from the following considerations. In free traffic, the total traffic outflow Q at the cross section of a respective effective bottleneck is the same size on average as the total upstream net traffic influx Qn to the localization point of the effective bottleneck, taking account of all approach roads and exits in the relevant region. In this case, the localization point of an effective bottleneck is that point where the downstream edge between synchronized traffic, which arises from the existence of this effective bottleneck, and free traffic is localized downstream thereof. In other words, this net traffic influx to the effective bottleneck is the total traffic flow of all vehicles which must be driven through the associated

localization point coming from all possible directions. The traffic flow at the cross section of each effective bottleneck is then limited in the state phase of synchronized traffic to a certain maximum traffic flow Q_{smax} which drops with a rising proportion of lorries in the traffic flow. Consequently if during a period Δt greater than a certain first minimum period Δt_1 the net traffic influx Qn is on average more than a certain first excess value ΔQ_1 above the maximum traffic flow Q_{smax} of the state phase of synchronized traffic, the "excess" vehicles, whose number is yielded as appropriate time integral over the flow difference, must be "stored" upstream of the localization point of the effective bottleneck.

This is the reason why in the state phase of synchronized traffic a pinch region can arise in which these excess vehicles are stored in the typical temporary "narrow" congestion point. The specified criterion $Qn-Q_{smax} \geq \Delta Q_1$ for a time interval $\Delta t \geq \Delta t_1$ can therefore be used as criterion for the production of the reduced pattern form in accordance with Figure 2, and most accurately when the net influx Qn corresponds to free traffic upstream of the upstream edge $F_{F,S}$ of synchronized traffic in accordance with Figure 1 for each direction of influx and outflow.

When the difference $Qn-Q_{smax}$ is on average above a second excess value ΔQ_2 during a period Δt greater than or equal to a second minimum period Δt_2, the second excess value ΔQ_2 being greater than the first excess value ΔQ_1 and/or the second minimum time interval Δt_2 being greater than the first minimum time interval ΔQ_1, it is necessary for yet more excess vehicles to be stored upstream of the localization point of the effective bottleneck, for which reason the region of moving widespread congestion arises upstream of the pinch region. In this case, the excess vehicles are

stored not only in temporary narrow congestion points, but also in lasting widespread ones. This criterion can therefore be used to detect a formation of the full pattern in accordance with Figure 3, and is at its most exact when the total net influx Qn corresponds to free traffic upstream of the upstream edge $F_{F,GS}$ of the pinch region in accordance with Figure 2, once again for each direction of influx and outflow.

Alternatively, another criterion can be formulated for the production of the region of moving widespread congestion upstream of the pinch region. This criterion is based on the fact that in a direction "j" of influx or outflow the region of moving widespread congestion arises upstream of the pinch region when the total associated net influx Qn_j of this direction "j" in the free traffic upstream of the upstream edge $F_{F,GS}$ of the pinch region in accordance with Figure 2 is sufficiently large by comparison with the average total flow $Q_{nout,j}$ in this direction "j" downstream of narrow congestion points of the pinch region. This alternative criterion points consequently to the production of the region of moving widespread congestion upstream of the pinch region when the difference $Qn_j-Q_{nout,j}$ for a period Δt of at least one associated third minimum period Δt_3 is on average greater than or equal to an associated third excess value ΔQ_3. In this case, for the three described cases the three minimum periods Δt_1, Δt_2, Δt_3 are, just like the three excess values ΔQ_1, ΔQ_2, ΔQ_3 for the respective effective bottleneck or for the respective group of effective bottlenecks which are responsible for an overarching pattern are prescribed variables, while the maximum traffic flow Q_{smax} in the synchronized traffic and the average total flow $Q_{nout,j}$ downstream of narrow congestion points of a direction "j" are variables whose values are to be determined from experimental traffic data for each effective bottleneck.

An overarching pattern which can be stored with its temporal and spatial characteristic and can be called up to be used for a traffic prediction can not only arise due to overlaps of regions of moving widespread congestion with regions of synchronized traffic and/or pinch regions, and with the movement of the congestion point, but can be realized at least by means of the two following processes.

In a first case, in the course of time the upstream end of a pattern of dense traffic firstly reaches the point of the effective bottleneck next upstream, after which the upstream end of the partial pattern, formed by the last effective bottleneck as upstream part of the further extending overarching pattern, of dense traffic reaches a bottleneck next upstream, etc. This process can last for hours and be predicted, since the development of each individual pattern at each effective bottleneck can be predicted as part of the overarching pattern. The corresponding characteristic of this process of the production and the further temporal and spatial development of the overarching pattern is stored and is available in a fashion which can be called up for a traffic prediction in the traffic network.

As a second case, it can be that the previously described process of the production of an overarching pattern is interrupted by virtue of the fact that the traffic volume in the surroundings of the effective bottleneck next upstream is too low for a pattern of dense traffic to arise there. However, at an effective bottleneck further upstream some moving congestion points can nevertheless once again trigger a pattern, corresponding to this bottleneck, of dense traffic. Because they propagate upstream, the congestion points can be situated at a relatively large distance of, for

example, several kilometres upstream of that pattern of dense traffic or of the associated effective bottleneck where they were originally produced in the associated region of moving widespread congestion. They can therefore move independently of the temporal and spatial development of the remainder of the pattern of dense traffic, and can therefore trigger new "full" or "reduced", or else "overarching" patterns at different upstream bottlenecks independently of whether the associated pattern of dense traffic otherwise still exists or not. All these processes can be stored in a fashion which can be called up for a prediction of the production of one or more individual patterns of dense traffic and/or one or more overarching patterns of dense traffic.

It may be remarked that the pattern formation processes described above are not to be understood only in terms of one dimension, but also comprise two-dimensional pattern formation processes in the two-dimensional traffic network by virtue of the fact that, for example, one or more patterns of dense traffic branch off upstream via corresponding approach roads, that is to say extend upstream onto a plurality of route sections of the traffic network, with the result that finally a two-dimensional, branched pattern of dense traffic can form.

Two application examples for the present method are illustrated in Figures 4 and 5 in a fashion combined with the method described in the parallel German patent application mentioned. Figure 4 shows the classification of the current and future traffic state at a measuring point M of the directional lane 1, for example, of a motorway or motor highway. The traffic intensity $q(t)$ and the average vehicle speed $v(t)$ are measured continuously, that is to say in a time-dependent fashion, at the measuring point M and fed to

a traffic centre for evaluation by a fuzzy logic system. This includes a unit 3 for fuzzifying the input variables, a fuzzy interference system 4 for deriving fuzzy result values by applying prescribable fuzzy rules to the fuzzified input variables, and a unit 5 for defuzzifying the fuzzy result values, that is to say for forming a crisp result value. Exactly one of the values of "free traffic", "synchronized traffic", "pinch region" or "congestion point" is output as a result for the current traffic state of the considered measuring point M, see block 6 in Figure 4. In the case of the use of predicted instead of current values of the traffic intensity q(t) and the average speed v(t) the fuzzy logic system outputs as a result the traffic state at the measuring point M predicted for this future point in time, see block 7 of Figure 4. The mode of procedure in the abovementioned parallel German patent application, to which reference may be made, is described to this extent.

The present method is based thereon and additionally provides a further-reaching traffic prediction which is based on the prediction information obtained in accordance with block 7 of Figure 4. Specifically, in this case the traffic state is classified in the fashion explained above with regard to the typical pattern of dense traffic for route sections upstream of effective bottlenecks of the traffic network, and the best-fitting pattern is selected from the stored pattern variants and associated profiles when the measuring point M forms an effective bottleneck and dense traffic forms upstream thereof because of a correspondingly large traffic volume, as illustrated by a block 8.

Figure 5 shows a method example which is largely similar to that of Figure 4 and additionally permits the detection of the upstream edge $F_{F,S}$ of a respective

region B_S of synchronized traffic even for positions $x_{F,S}$ between two measuring points A, B, including a prediction of this edge position $x_{F,S}$ even in such intermediate regions, see block 9 of Figure 5. It is possible to this extent to refer once more to the description of this functionality in the abovementioned, parallel German patent application. The present method example is based thereon and uses the prediction data, obtained in accordance with block 9, on the extent and position of a respective region B_S of synchronized traffic to make a further-reaching traffic prediction of the dense traffic forming there and in the region upstream thereof in accordance with the finding explained above and the temporal tracking of the associated typical pattern of dense traffic when the dense traffic is to be ascribed to an effective bottleneck in whose surroundings a downstream edge of the region B_S of synchronized traffic remains fixed. As specified in block 10 of Figure 5, for this purpose the predicted traffic data for this route section are used to select the best-fitting pattern variant of dense traffic from those stored, which is then used for further evaluation purposes and, in particular, prediction purposes.

It goes without saying that, as explained above, the mode of procedure described above with the aid of Figures 4 and 5 can be used not only to determine current and predict future individual patterns of dense traffic in which only in each case one effective bottleneck is involved, but also current or future "overarching" patterns of dense traffic in which in each case a plurality of effective bottlenecks are involved. In this case, the method is applied in parallel for the plurality of effective bottlenecks of a respective overarching pattern which are involved.